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ANALYZING GAIT USING THE DYNAMICS OF A MATHEMATICAL MODEL?

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Jordan

ABSTRACT

Athletes need modeling and feedback to reach for their maximum performance, computer simulation is not the only nontraditional modern development in biomechanics. Dynamical system approach (DSA) is another fascinating enlargement in the field of biomechanics.

The purpose of this study was to investigate the practicability of this assessment by showing the dynamics of the movement and the differences in movement patterns by comparing the frequency patterns of the gait of the different subject groups.

Three different groups were examined in this study. These groups were: control patient group (CP), senior group (S), and sport student group (SS). The CP-group was composed of (9)patients ,the S-group and the SS-group had no neurophysiological diseases and were composed of 17 senior.

Results showed that the S-group and the SS-group resembled patterns and data with the difference of higher peaks at the beginning and a higher gradient between the first peaks for the seniors. The CP-group shows much lower peaks in the beginning and higher peak values to the end, also the differences between both sides of the body are obvious in comparison to the normal gait of the SS-group.

Key word: analyzing gait, mathematical model

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Introduction

A coach or an athlete needs information that allows him or her to compare the own performance with that of other athletes. Information on movement pattern, force progression, timing etc. serve the purpose very well. Those measurements in most cases can be achieved using standard equipment, like cameras together with digitizing systems, force platforms, pressure mats, goniometers etc. Standard equipment and standard procedures have the enormous advantage of being simple to operate and to be available to a wider audience. Graphs allow easily communicating findings to the practitioners. However, many aspects of a performance are hidden within abstract parameters as energy, angular momentum, time dependent inertia tensors etc. Such concealed parameters are calculable with the help of simulation systems (Figure 1). But there is a price to pay. The findings are harder to communicate and the expenditure of work can be enormous. Detailed simulation models when created from scratch need years for the development. In the case of Human-Builder (the Vieten's development) in connection with SD 6.2 the software evolution took more than 10 years. Buying a simulation system is surely a faster way to develop a modern research alley. However, computer simulation is not the only nontraditional modern development in biomechanics. Dynamical system approach (DSA) is another fascinating enlargement in the field of biomechanics. The beginning of the advances in biomechanics began with the work of Bernstein (1967). Within physics methods were used already decades ago, which provide a natural realization to a DSA the description of a moving system in terms of phase space. Phase space is a mathematical space that represents all states of a system. Usually it consists of all coordinates and momentums of a physical system. In terms of human movement coordinates and velocity (velocity is connected to momentum via $\vec{p} = m \cdot \vec{v}$) institute phase

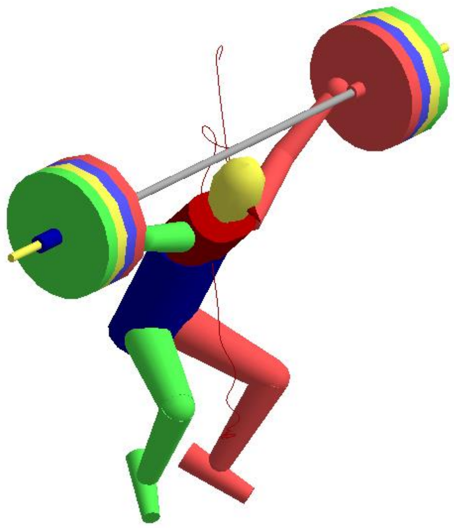

Figure 1: Simulation of a weightlifter

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space. For example the n marker coordinates connected to a human body and the n respective velocities establish a $2n$-dimensional phase space and hence fully describe the movement. For many research questions it is not necessary to look at the full phase space. Often, a small subset of the space very well describes the feature under observation. As an example let's take fatigue in running. The temporary standard procedure to judge fatigue is taking a lactate measurement. But can fatigue be identified from movement pattern? The running athlete is a system with many degrees of freedom. Hence, a multidimensional vector space would fully describe the movement. However, can just one parameter, say the distance d between the left hip joint and the tip of the left foot as a function of time, contain enough information to identify a certain degree of fatigue? In the author's opinion this measure or a similarly simple one might keep a key to measuring fatigue. To determine d a digitizing system with just two markers produces suitable data. Next step in the methodology is filtering, followed by calculating the first derivative and thereafter the plot of the phase space (**Error! Reference source not found.**). All these steps and the following in the research process are easily done and with a minimum in time and equipment involved. The average of all steps for a period of 1500 frames at the beginning of the run and at the end of the run show substantial differences (see Figure 3). So far, the experimental expense is minimal and also the time for the calculation is bearable. Vieten, (2006) developed for that reason the software StatFree, which does the analysis and the graphic display. The software can be downloaded from the internet at http://www.uni-

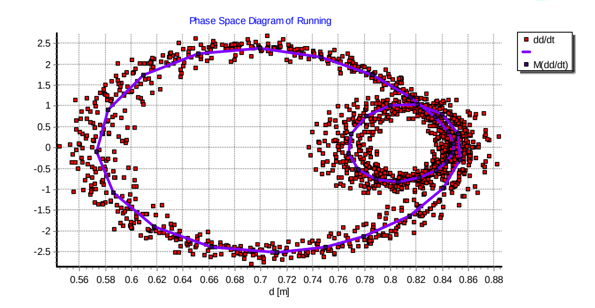

Figure 2: Phase Space Diagram of Running

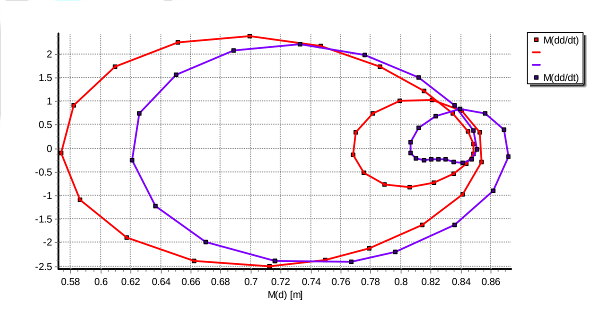

Figure 3: Averaged Phase Space Diagram of Running without (wider curve) and with (smaller curve) fatigue

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konstanz.de/FuF/SportWiss/vieten/Software/. Still, the result/graphics are not interpreted and an indicator for fatigue is not identified. Ideas from chaos theory might help to get a robust identifier. A deterministic system can show chaotic behavior if the governing equations are nonlinear. It is not necessary to set up the equations of a running human. If the system is nonlinear it might eventual show chaotic behavior regardless if the equations are known or not. The crossing of a system from a stabile state into a chaotic state is hallmarked by period doubling (Williams 1997). The velocity as a function of time is shown in Figure 4.

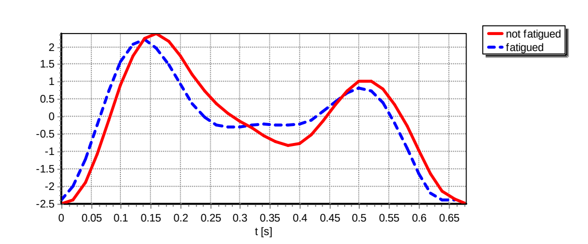

Figure 4: Velocity

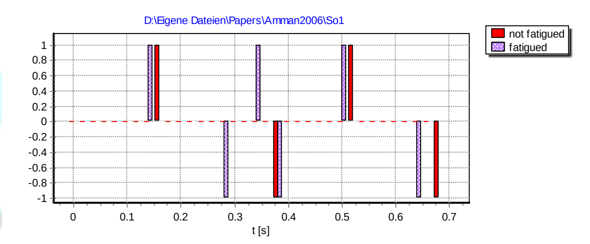

Figure 5: Minima and maxima of the Velocity Curve

This curve gives a first impression of the changes but Figure 5 shows much clearer where the differences occur. Here a first step toward the identification of fatigue via biomechanical investigations is done. Surely, more statistics and the comparison with other methods is necessary. However, what I wanted to demonstrate is that beside the traditional "descriptive" studies (standard equipment and a moderate amount of work expenditure) and the simulations approach (usually with lots of effort, lots of equipment) a third avenue the "dynamical system approach" exists. DSA promises new and existing views of new and old problems while the expenditure in equipment and time is also affordable for smaller research groups.

The purpose of this study was to investigate the practicability of this assessment by showing the dynamics of the movement and the differences in movement patterns by comparing the frequency patterns of the gait of the different subject groups.

Methodology

Three different groups were examined in this study. These groups were: control patient group (CP), senior group (S), and sport student group (SS). The CP-group was

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composed of 9 patients (38.3 ±6.7 years; mean of individually chosen walking speed: 2.04 ±0.56km/h) diseased by hemi paresis (n=3) or cerebral palsy with spasticity (n=6). Patients with hemi paresis optically showed an extremely one-sided moving pattern and should show a significantly different frequency pattern of gait between both sides. Patients with cerebral palsy had different kinds of spasticity and because of the noncircular steps, their frequency patterns should also differ from those of healthy subjects. The S-group and the SS-group had no neurophysiological diseases and were composed of 17 seniors (68.5 ±5.7 years; walking speed: 2.56 ±0.79km/h) and 14 students (26.3 ±2.5 years; walking speed: 3.70 ±0.54km/h). The senior group should display a changed frequency pattern because of changes of gait of elderly people. The subjects had to walk on a treadmill at their individual speed with the intention not to get fatigued early and to secure the patients. All subjects walked at their individual speed by holding at both sidebars to get comparable movement patterns. A motion analysis was investigated with three infrared cameras at a frequency of 100Hz by Lukotronic System (LUKOtronic Lutz-Kovacs-Electronics OEG, Innsbruck, Austria). The system was installed behind the treadmill at a distance of 1.5m and a height of 1.2m. Eleven reflected markers were placed at the backside of the subjects. These placement of the markers were: shoulder left, shoulder right, sternum, hip left, hip right, knee left, knee right, ankle left, ankle right, heel left, and heel right(Muller, Vieten & Kilani, 2012) (Figure 1). Two days before the measurement subjects had an adaptation phase over twenty minutes walking on the treadmill. After a warming up period on the treadmill the movement patterns of the subjects were measured over a period of two minutes.

Background of this study is the motion analysis of Bernstein (1967), who investigated kinematical chains as a framework. Therefore, the scalar product of the distance between shoulder and ankle was investigated using a Fast Fourier Transform (Figure 2). This distance has been chosen because of plenty involved degrees of freedom. To amplify the higher harmonical frequencies, the distance data was differentiated with respect to time two times. To be independent of individual walking speed, the frequency data was normalized afterwards. The area under the first peak (fundamental frequency) and the nine following peaks (higher harmonical frequencies) were measured. Means of the ten areas were calculated and compared to the three different groups.

Another parameter was the quality of the movement (MQ). The MQ is described in a score, generated by a mathematical formula to depict the quality of gait in a simplified

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way. The mathematical formula was generated to discriminate the different movement patterns with regard to walking speed, gradient between the peaks and the difference between left and right body side. The quality of movement (MQ) was applied to the Fast Fourier Transform of the ankle-data. Fundamental frequency and five higher harmonical frequencies were included. For comparison the MQ mean reference peak values were calculated for the 14 measured students, who simulated a normal gait. The standard deviation of the mean values created a range, where peak values for movement patterns of normal gait should lie in-between (Figure 3). Otherwise a subtraction from the maximum score of 100 should express the MQ using the following formula:

$$MQ = \left[100 - \sum_{i=0}^{5}\left(P_{N,i} - P_{P,i}\right) - \sum_{i=0}^{5}\left|S_{N,i} - S_{P,i}\right| - \sum\left|R_P - L_P\right|\right] \cdot \frac{v}{3}$$

PN,i = peak value reference
PP,i = peak value subject
SN,i = gradient reference
SP,i = gradient subject
RP = sum difference ankle right (subject)
LP = sum difference ankle left (subject)
v = individual walking speed
i = fundamental frequency and four higher harmonical frequencies

The MQ of the subjects had a possible range of 0-100 classified in three groups. The formula allows negative values that were displayed as a MQ of 0:(table 1 near here)

Results

The frequency patterns of the FFT of the subjects arranged in the three groups are presented in figure 4. The S-group and the SS-group showed resembled patterns and data with the difference of higher peaks at the beginning and a higher gradient between the first peaks for the seniors. This effect might be linked to the much higher ratio of step frequency to the individual walking speed of the seniors compared to the other groups. Especially for the more affected side the pathological gait of the CP-group shows much lower peaks in the beginning and higher peak values to the end. Also the differences

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between both sides of the body are obvious in comparison to the normal gait of the SS-group.

The results of the calculations of the MQ are given in Figure 5. The SS-group and the CP-group showed realistic values, especially for the patients where high standard deviation reflects higher variability of the gait during the whole recording. The differences between more (17.1 ±31.9) and less affected side (39.7 ±15.4) of the hemi paresis patients were clear as well. The S-group showed by far the lowest values. Particularly this group exhibits a high variability (Figure 5) compared to the SS-group and the CP-group.

Discussion & Conclusion

The frequency patterns of the FFT showed a sort of an individual fingerprint for each subject. Arranging all subject data in the three groups, the results were three different but typical frequency patterns that displayed differences between normal and pathological gait, as well as gait of elderly people. The standard deviation and also the absolute range of peak values of different FFT movement patterns show the individual shape but also a clear tendency. Therefore the practicability of the Fast Fourier Transform to display movement patterns in an objective way is basically given.

The application of the formula for the MQ showed generally realistic values. For most subjects except of the senior group the MQ score was in the expected area. That means that because of the high variation of walking styles due to different states of health of seniors, this formula cannot be applied for the physical examination of elderly people.

One limitation of this study is the low subject pool including a high variability in severity of diseases and individual walking speed. In further studies the amount of subjects should be increased and therefore a classification of the severity of diseases could be done. Also the difference between treadmill and over ground walking should be considered in the results of this study. It could be concluded that the application of this new methods (FFT movement patterns) will add to the biomechanics of the gait analysis as to stereotyped the gait of different group patterns and classify them with respect to fatigue/ no-fatigue patterns as a finger thump.

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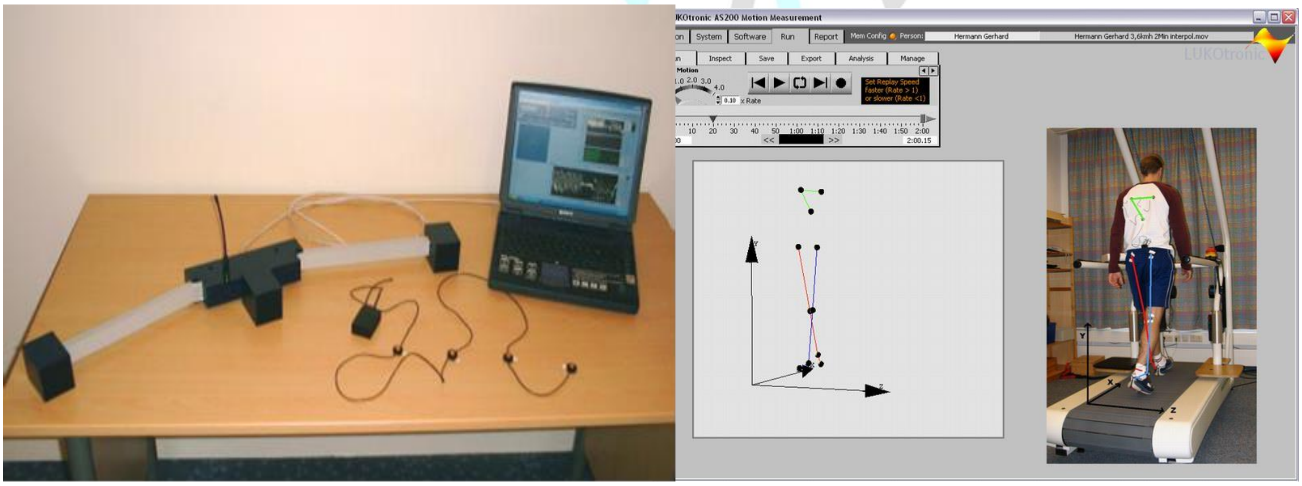

Figure 1: LUKOtronic hardware (left) and subject on treadmill using the LUKOtronic software (right)

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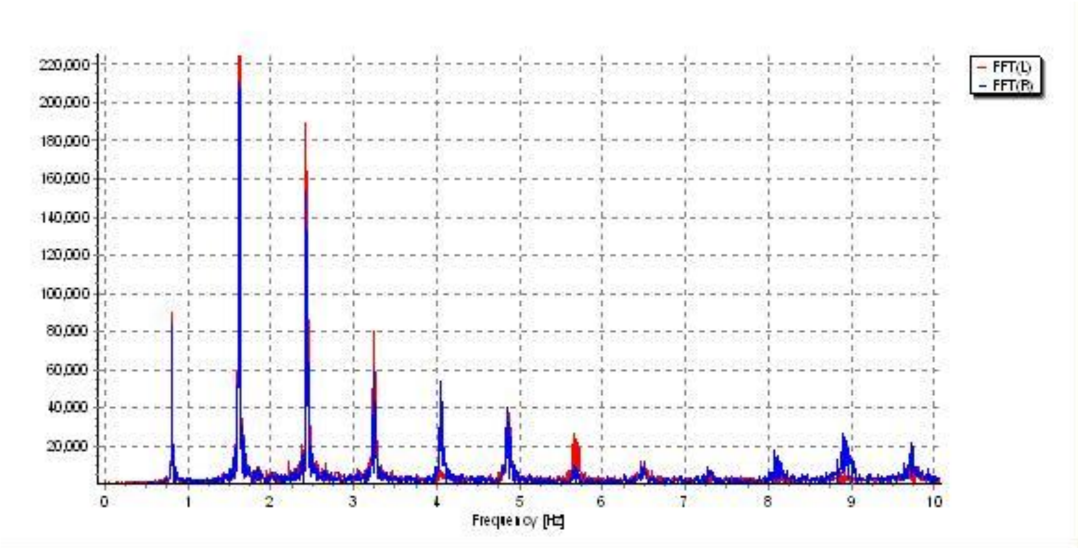

Figure 2: Distance shoulder-ankle using FFT

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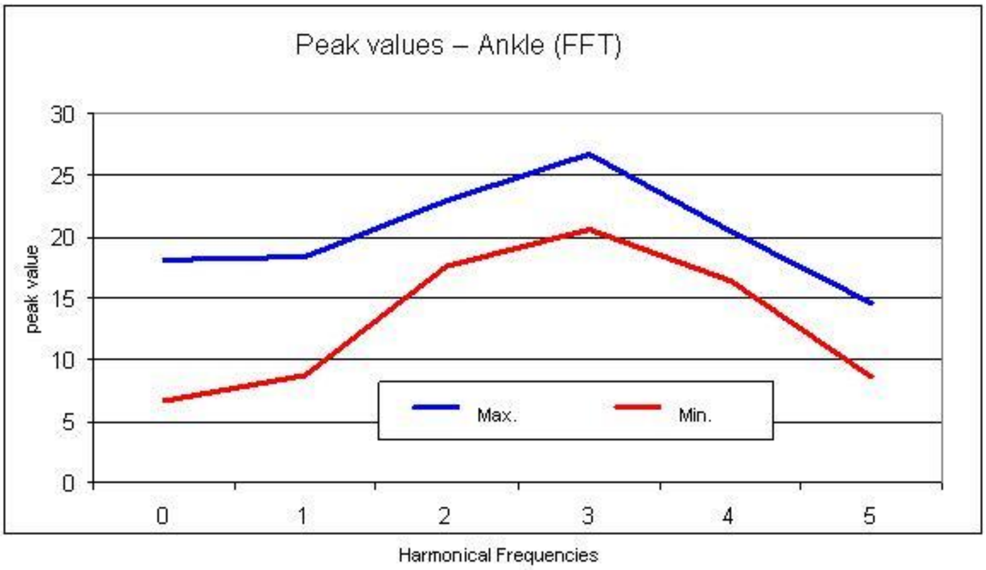

Figure 3: Range FFT (Ankle)

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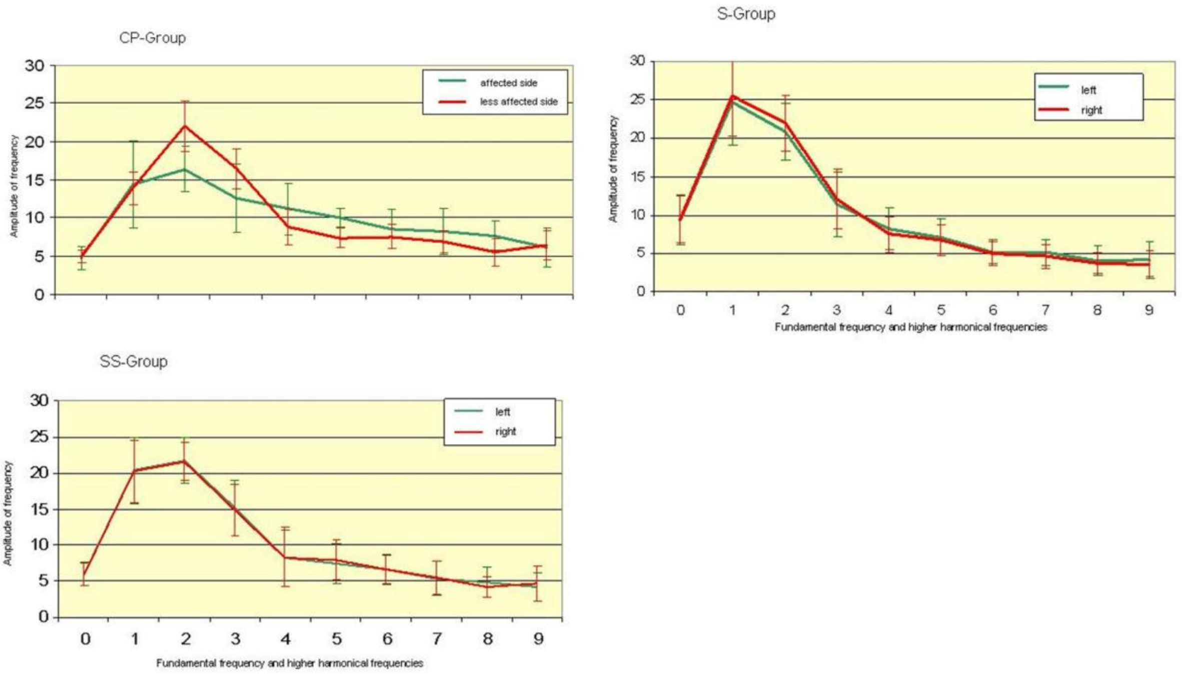

Figure 4: Shoulder-Ankle (FFT) with standard deviations.

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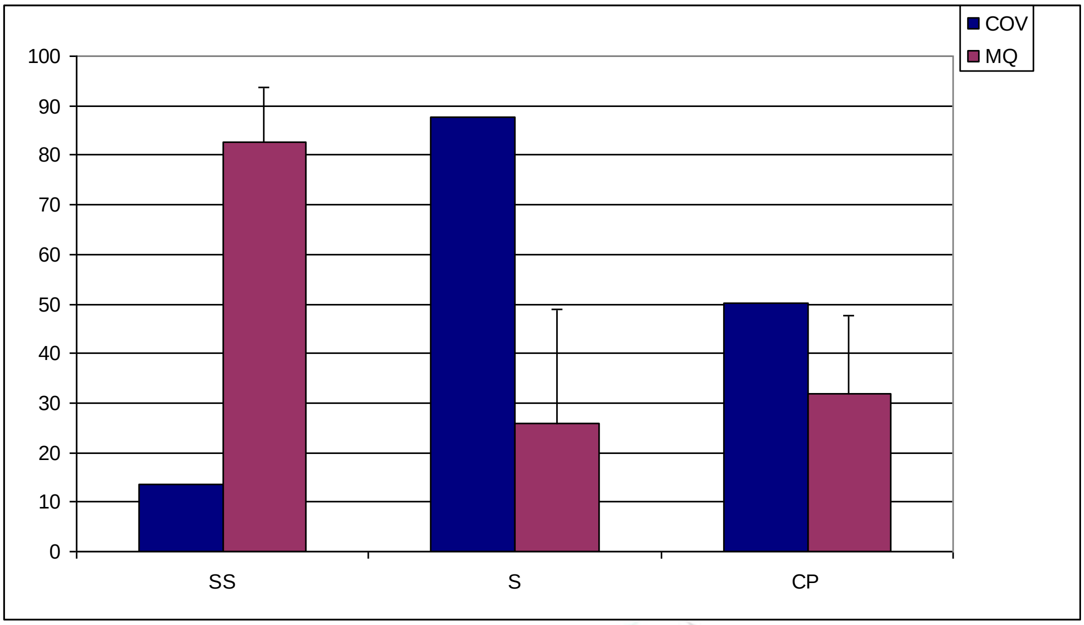

Figure 5: Movement quality (MQ) and coefficient of variability (COV)

Table 1: Classification of the MQ

100	–	70	=	normal gait
70	–	40	=	gait with limitation
40	–	0	=	pathological gait

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